Towards an improved estimate of antimicrobial use in animals: Adjusting the "population correction unit" calculation

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Abstract

International comparisons of animal antimicrobial use (AMU) have typically been based on total national estimates of antimicrobials sales standardized by the national animal biomass calculated as the population correction unit (PCU). The objective of this paper was to compare the currently accepted PCU calculation with that of the adjusted population correction unit (APCU), which re-evaluates the standard animal weights used in the calculation and accounts for animal lifespan. The APCU calculation resulted in substantial changes to the 2009 national biomass estimates for cattle, pigs, and poultry in 8 European countries and Canada. The estimated national biomass for cattle increased 35% to 43%, while the estimated national biomass of pigs and poultry typically decreased by approximately 51% and 87%, respectively. Among the 9 countries, the total national APCU ranged from an increase of 1% to a decrease of 40% relative to PCU, and these differences were statistically significant. Adjusted population correction unit is preferred over PCU in comparing and contrasting AMU among animals with different lifespans because it is more transparently derived and is a reasonable approximation of the animal biomass at risk of antimicrobial treatment.

Résumé

Les comparaisons internationales de l'utilisation d'antimicrobiens chez les animaux (UMA) ont typiquement été basées sur les totaux nationaux estimés de ventes d'antimicrobiens standardisés pour la biomasse animale nationale calculée comme l'unité de correction pour la population (UCP). Les objectifs de cet article étaient de comparer les calculs d'UCP présentement acceptés à ceux de l'unité de correction pour la population ajustée (UCPA), qui réévalue les poids animaux standards utilisés dans les calculs et tient compte de la durée de vie des animaux. Les calculs de l'UCPA ont entrainé des changements substantiels aux estimés nationaux de 2009 de la biomasse pour les bovins, porcs et volailles dans 8 pays européens et le Canada. La biomasse nationale estimée pour les bovins a diminué de 35 % à 43 %, alors que les biomasses nationales estimées pour les porcs et les volailles ont typiquement diminué d'environ 51 % et 87 %, respectivement. Parmi les neuf pays, l'UCPA nationale totale variait d'une augmentation de 1 % à une diminution de 40 % relativement à l'UCP, et ces différences étaient statistiquement significatives. L'UCPA est préférée par rapport à l'UCP pour la comparaison et la mise en contraste de l'UMA chez les animaux avec différentes durées de vie étant donné qu'elle est dérivée de manière plus transparente et qu'elle est une approximation raisonnable de la biomasse animale à risque d'un traitement antimicrobien.

(Traduit par Docteur Serge Messier)

Due to global public health concerns, antimicrobial use (AMU) in animals is of significant interest, including international comparisons of AMU. These comparisons have typically been based on total national estimates of antimicrobials sales standardized by the national animal biomass calculated as the population correction unit (PCU). This approach has been criticized in favor of daily defined dose animals metrics (DDDA) which account for drug potency and usage at a species level, if not by animal age or weight (1). However, current and future implementation of DDDA is hampered by its high resource demands (2), including antimicrobial use by species, if not by animal age or weight, and the lack of a global DDDA standard. A European Union standard that has been under development since 2012, has recently been released and addresses poultry, pigs, and cattle while recognizing the need for DDDAs for all food producing species including other ruminants, horses, fish, rabbits, and companion animals (2,3).

In contrast, national estimates of antimicrobial usage standardized using PCU are available for over 25 countries, including Canada, and encompass use in all food-producing species (4). Therefore, for the foreseeable future it is likely PCU will continue to be used in international comparisons of animal AMU, as well as in comparison of usage between species (5).

The purpose of PCU is to control for animal demographics, which can vary over time within a country, and between countries. The PCU is calculated by totalling the number of livestock or poultry in an animal category multiplied by a standardized theoretical weight of an animal in that category at the age it would most likely be treated with antimicrobials, which is called average weights at treatment (AWT) (6).

There are 2 potential problems with the PCU method for calculating animal biomass. Firstly, it is not clear how AWT is estimated

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or how it is related to antimicrobial use. Instead, PCU calculations typically reference Monforts (7) and the European Medicines Agency (8), that simply define AWT as the mean body weight for animals raised for slaughter, and the maximum body weight for other animal groups (e.g., breeding animals). Even based on these definitions, some of the currently used AWT values do not appear to accurately reflect animal weights. For example, the average mature cow weighs approximately 600 kg (9–12), while a weight of 425 kg is currently used for PCU calculations.

Antimicrobial use in an animal population is affected by the weight of the animals, and their length of life. The opportunity for antimicrobial use increases with increased length of life, and length of life of PCU's livestock and poultry categories vary considerably. The PCU doesn't take into account length of life (4) and this is the second concern with the PCU method of estimating animal biomass. The PCU's failure to incorporate the variable lifespans of the animal categories has potential implications not only for AMU comparisons between species, but also for comparisons of total national usage. This failure potentially results in underestimation of AMU in countries with a preponderance of short-lived animal categories, such as poultry, and overestimation in countries with disproportionately more longer-lived categories such as cattle.

It is important that PCU calculations accurately reflect animal biomass for the animal categories of interest because inaccurate PCU values may lead to erroneous conclusions when comparing and contrasting AMU data. The objective of this paper is to compare the currently accepted PCU biomass calculation with one that re-evaluates AWT (based on current data regarding production animal weights) and accounts for the lifespan of the animal categories in question, using data from 8 European countries and Canada.

Currently, a country's PCU is calculated as follows:

$$\text{PCU} = \sum_c n_c AWT_c - \sum_i n_i AWT_i + \sum_e n_e AWT_e \qquad \textit{(Equation 1)}$$

where n_j is the total number of animals in category j (i.e., for breeding animals, n_j is the number of animals present in a year; if j are slaughter animals, n_j is the total number of animals slaughtered annually); AWT_j is the average weight at treatment of an animal in j (kg); c is the animal categories raised and slaughtered within the country in question; i is the animal categories imported to the country; and e is the animal categories exported from the country.

The proposed equation, adjusted PCU (APCU), is as follows:

$$\text{APCU} = \sum_c n_c LAW_c - \sum_i n_i LAW_i + \sum_e n_e LAW_e \qquad \textit{(Equation 2)}$$

where LAW_j is the life adjusted weight of an animal in category j. Life adjusted weight *(LAW)* is calculated as:

$$LAW_j = AW_j LL_j \qquad \textit{(Equation 3)}$$

The AW_j is the adjusted weight of an animal in j (kg) calculated using Monforts' (7) and the European Medicines Agency's (8) definitions of the animal weights (i.e., the mean weight for slaughter animal categories and the maximum weight for all other animal categories). The LL_j variable is the length of life for category j animals as measured in years.

For the animal categories most commonly included in PCU calculations, established AWT values were obtained from the European Medicines Agency (6) (Table I).

Adjusted weights (AW) were arrived at in several different ways depending on the data available. For the cattle categories, the slaughter (ending) weights were calculated by dividing the average carcass weight by a live-to-carcass weight conversion factor (13) to determine the average weight of live animals. Average carcass weights for 28 EU countries were calculated by dividing the total animal weight at slaughter for a given animal category, by the number of animals slaughtered for that category (14). Subsequently, using Monforts' definition, the mean body weight of the cattle slaughter categories was calculated by averaging a birth weight of 45 kg and the final weight at slaughter. The AW of imported and exported cattle for slaughter is the mean weight of slaughter heifers, bullocks, and bulls.

For the remaining animal categories, Eurostat data regarding carcass weights and number of animals slaughtered were not available. For this reason, the international literature was reviewed to provide a contemporary estimate of animal weights in each category. It was determined that these AWT are generally consistent with the (average) body weights defined elsewhere (9–12), including Canadian PCU calculations (Canadian Integrated Program for Antimicrobial Resistance personal communication, 2016). The AWT was therefore used as AW for the non-cattle categories with the exception of pigs imported or exported for fattening. The AWT of these pigs is 25 kg. However, Monforts (7) and the European Medicines Agency (8) include weight of piglets up to 25 kg in the sow weight so the AW for exported fattening pigs was set to zero (Table I). Similarly, the 25 kg AWT for imported fattening pigs was set to zero as this weight is already recognized as the beginning weight in the slaughter pig's category (Table I).

An animal category's length of life (LL) was calculated using the inverse of its number of cycles per year on an average farm. For example, if the typical broiler farm has 9 cycles per year, then the average LL for broiler chickens is 0.11 y (1/9). Data regarding the number of cycles per year for each animal category were obtained from Monforts (7) and the European Medicines Agency (8). Neither reference included the number of cycles for slaughter heifers, bullocks or bulls. A LL of 1.5 y is assigned to slaughter heifers, bullocks, and bulls based on knowledge of these industries.

Using the most recently published values of n for the 8 European countries (6) and Canadian data (Canadian Integrated Program for Antimicrobial Resistance personal communication, 2016), and AWT (Table I), the 2009 PCU for the 9 countries was reproduced using Equation 1. The APCU for each country was calculated using Equation 2, the same values of n, and LAW from Table I. A 2-tailed paired t-test was used to determine whether total PCU and total APCU were significantly different among countries using Stata v.13.1 (StatCorp, College Station, Texas, USA) and APCU as a percentage change from PCU [i.e., (APCU-PCU)/PCU $\times$ 100%] was calculated.

The 2009 PCU for the 9 countries is reported in Table II, as is the APCU and the percentage change. For cattle, APCU was 35% to 43% greater than PCU for each of the 9 countries, while for pigs, poultry, sheep, and goats, the APCU was consistently less than the PCU. For example, using APCU, the national poultry biomass decreased by 81% to 89%. The estimated national biomass of horses and fish were

Table I. Animal categories, population correction unit (PCU), average weight at treatment, and data used in calculating life adjusted weights

Animal category	PCU average weight at treatment (AWT) (kg)	Adjusted weight (AW) (kg)	Length of life (LL) (year)	Life adjusted weight (LAW) (kg year)
Cattle				
Slaughter cows	425[a]	627	1	627
Slaughter heifers	200[b]	269 (45, 493)[e]	1.5	404
Slaughter bullocks and bulls	425[a]	329 (45, 612)[e]	1.5	494
Slaughter calves and young cattle	140[c]	169 (45, 293)[e]	0.56	94
Imported/exported cattle for slaughter	425[a]	299[j]	1.5	449
Imported/exported cattle for fattening	140[c]	169 (45, 293)[e]	0.56	94
Livestock dairy cows	425[a]	627	1	627
Pigs				
Slaughter pigs	65[d] (25, 105)[e]	65	0.33	22
Imported/exported pigs for slaughter	65	65	0.33	22
Imported/exported pigs for fattening	25[f]	0		
Livestock sows	240[g]	240	1	240
Poultry				
Slaughter broilers	1	1	0.11	0.11
Slaughter turkeys	6.5	6.5	0.37	2.4
Imported/exported broilers for slaughter	1	1	0.11	0.11
Sheep and goats				
Slaughter sheep and goats	20 (NA[h], 40–45)[e]	20	0.5	10
Imported/exported sheep and goats for slaughter	20	20	0.5	10
Livestock sheep	75	75	1	75
Horses				
Living horses	400[i]	400	1	400
Fish				
Slaughter fish[k]				
Rabbits				
Slaughter rabbits	1.4	1.4	0.15	0.21

[a] Adult cow weight.
[b] 0-1-year-old bovine weight.
[c] Veal calf weight.
[d] Fattening pig (25 to 105 kg).
[e] Beginning weight for animal category, ending weight for animal category.
[f] Weaner pig (to 25 kg).
[g] Weight for sow and piglets until 25 kg.
[h] Not available.
[i] Horses 600 kg, ponies 250 kg.
[j] The mean of a slaughter heifer, bullock, and bull weight (i.e., 269 + 329/2).
[k] Eurostat data available only as live-weight at slaughter; information on AWT is unavailable.

the same for APCU and PCU. The estimated national biomass for slaughtered rabbits decreased for France and Canada.

For each country as a whole, the difference between APCU and PCU was variable. For Finland and Norway, APCU was respectively 11% and 1% greater than PCU. For the remaining 7 countries, APCU was between 2% and 40% less than PCU. The APCU and PCU were statistically significantly different ($P = 0.02$, $t = 3.01$, d.f. = 8) for the 9 countries.

Use of the 2 different animal biomass calculations (APCU *versus* PCU) resulted in substantially different national values for most animal categories included in this analysis, as well as for most of the countries as a whole. These differences could have substantial

Table II. Calculation of population correction unit (PCU), adjusted population correction unit (APCU), and APCU as a percentage change (% Δ) from PCU for 8 European countries and Canada, 2009 (1000 tonnes)

	Czech Republic			Denmark			Finland			France			Netherlands		
Animal category	PCU	APCU	% Δ	PCU	APCU	% Δ	PCU	APCU	% Δ	PCU	APCU	% Δ	PCU	APCU	% Δ
Cattle	308	421	37%	403	566	41%	227	319	41%	3289	4437	35%	1009	1401	39%
Slaughtered cows	52	76		80	119		36	53		756	1115		216	319	
Slaughtered heifers	5	10		9	18		7	14		85	172		3	6	
Slaughtered bullocks and bulls	47	54		47	55		62	72		500	581		26	30	
Slaughtered calves and young cattle	2	1		19	13		0	0		220	148		208	139	
Net exported cattle for slaughter	30	32		0	0		0	0		18	19		1	1	
Net exported cattle for fattening	9	6		3	2		0	0		148	99		0	0	
Net imported cattle for slaughter	0	0		0	0		0	0		0	0		0	0	
Net imported cattle for fattening	0	0		0	0		0	0		0	0		109	73	
Livestock dairy cows	163	241		244	360		122	179		1561	2303		664	979	
Pigs	245	116	−53%	1820	768	−58%	190	88	−54%	1941	836	−57%	1484	668	−55%
Slaughtered pigs	211	70		1255	418		152	51		1619	540		898	299	
Net imported pigs for slaughter	3	1		0	0		0	0		0	0		0	0	
Net exported pigs for slaughter	0	0		80	27		0	0		37	12		315	105	
Net exported pigs for fattening	0	0		162	0		0	0		0	0		7	0	
Net imported pigs for fattening	9	0		0	0		0	0		0	0		0	0	
Livestock sows	47	47		323	323		37	37		284	284		264	264	
Poultry	154	17	−89%	112	12	−89%	57	8	−86%	1179	229	−81%	400	44	−89%
Slaughtered broilers	136	15		100	11		51	6		759	84		481	53	
Slaughtered turkeys	0	0		0	0		6	2		377	140		0	0	
Net exported broilers for slaughter	18	2		12	1		0	0		43	5		0	0	
Net imported broilers for slaughter	0	0		0	0		0	0		0	0		81	9	
Sheep and goats	15	15	−1%	9	8	−11%	8	8	−5%	677	621	−8%	103	93	−10%
Slaughtered sheep and goats	0	0		2	1		1	0		105	52		15	8	
Net exported sheep for slaughter	0	0		0	0		0	0		8	4		6	3	
Livestock sheep	15	15		7	7		7	7		565	565		82	82	
Livestock horses	28	28	0%	70	70	0%	29	29	0%	168	168	0%	58	58	0%
Live weight fish slaughtered	20	20	0%	34	34	0%	14	14	0%	234	234	0%	56	56	0%
Slaughtered rabbits	0	0	0%	0	0	0%	0	0	0%	52	8	−85%	0	0	0%
Total	771	617	−20%	2447	1458	−40%	524	465	11%	7540	6533	−13%	3109	2321	−25%

effects on international comparisons of AMU as well as national comparisons among animal categories. For example, using PCU as the denominator, 2009 AMU in UK cattle is over 3-fold greater than AMU in pigs and poultry (5). In contrast, 2009 AMU in UK cattle is less than the AMU in pigs and poultry when APCU is used as the denominator (calculations not shown). These differences are primarily attributable to including length of life in the calculation, although for cattle categories and traded fattening pigs, adjusting the weights used in the calculation also had an impact. Given that analyses of AMU rely on accurate estimation of animal biomass to enable comparisons among animal categories and between countries, these results have significant implications on how AMU is calculated.

Amending or replacing the conventional PCU biomass calculations with the APCU calculation presented here should be considered for 2 reasons. First, the APCU uses weight values that are clearly defined and supported by current data regarding animal weights. For example, cattle AW estimates using Canadian data yielded results similar to the Eurostat data. In the future, AW values could be further improved by collecting international contemporary weight data for all animal categories as is currently collected for cattle. The European Medicines Agency has revised the weight for beef and dairy cows upwards to 500 kg in their DDDA calculations (2), but these weights remain less than those suggested by the Eurostat data (Table I).

Second, although PCU is controlling for animal demographics which vary among countries and includes standardizing for differences in animal weights, it does not include controlling for differences in animals' lifespans (4). Bondt et al (1) objected, in principal, to the PCU approach of adding weights of breeding stock to those of animals slaughtered during the year without accounting for length of life because this approach does not accurately reflect the population at risk for antimicrobial treatment. The DDDAs used in

Table II. (continued)

Animal category	Norway			Sweden			United Kingdom			Canada		
	PCU	APCU	% Δ	PCU	APCU	% Δ	PCU	APCU	% Δ	PCU	APCU	% Δ
Cattle	231	315	36%	331	456	38%	1678	2395	43%	3925	5490	40%
Slaughtered cows	51	75		65	95		204	301		276	407	
Slaughtered heifers	0	0		11	21		156	315		215	434	
Slaughtered bullocks and bulls	76	89		96	111		537	623		703	816	
Slaughtered calves and young cattle	2	1		10	6		6	4		41	28	
Net exported cattle for slaughter	0	0		0	0		0	0		324	342	
Net exported cattle for fattening	0	0		0	0		0	0		40	27	
Net imported cattle for slaughter	0	0		0	0		14	15		0	0	
Net imported cattle for fattening	0	0		0	0		3	2		−6	−4	
Livestock dairy cows	102	150		150	222		792	1169		2332	3440	
Pigs	32	27	−16%	231	103	−56%	674	306	−55%	1874	793	−58%
Slaughtered pigs	8	3		192	64		587	196		1352	451	
Net imported pigs for slaughter	0	0		0	0		32	11		0	0	
Net exported pigs for slaughter	0	0		1	0		0	0		78	26	
Net exported pigs for fattening	0	0		0	0		0	0		128	0	
Net imported pigs for fattening	0	0		0	0		2	0		0	0	
Livestock sows	24	24		38	38		121	121		316	316	
Poultry	71	8	−89%	76	9	−88%	942	131	−86%	718	116	−84%
Slaughtered broilers	71	8		73	8		839	93		620	69	
Slaughtered turkeys	0	0		3	1		101	37		140	52	
Net exported broilers for slaughter	0	0		0	0		2	0		12	1	
Net imported broilers for slaughter	0	0		0	0		0	0		−54	−6	
Sheep and goats	92	80	−13%	46	43	−6%	1915	1758	−8%	56	49	−13%
Slaughtered sheep and goats	24	12		5	3		308	154		16	8	
Net exported sheep for slaughter	0	0		0	0		6	3		−1	0	
Livestock sheep	68	68		41	41		1601	1601		41	41	
Livestock horses	14	14	0%	141	141	0%	520	520	0%	417	417	0%
Live weight fish slaughtered	0	0	0%	0	0	0%	197	197	0%	142	142	0%
Slaughtered rabbits	0	0	0%	0	0	0%	0	0	0%	1	0	−100%
Total	440	443	1%	825	752	−9%	5925	5307	−10%	7133	7007	−2%

the Netherlands (15) and Denmark (16) account for animal lifespan. The LL used in the APCU calculations are representative of Canadian production practices.

Population correction unit is a purely technical unit of measurement and not a real value for the animal population biomass that could potentially be treated with antimicrobial agents (6). By adjusting the animal weights and incorporating length of life, the APCU approach is an improved approximation of the *actual* animal biomass at risk of antimicrobial treatment.

Using a calculation that better reflects average weights and includes length of life for each animal category resulted in values for total annual animal biomass that were significantly different than those obtained using a traditional PCU calculation. As a result, APCU provides a reasonable approximation of the actual animal biomass at risk of antimicrobial treatment. Consideration should be given to replacing PCU with APCU in AMU calculations comparing and contrasting AMU among animals with different lifespans. The methodology used to transparently derive APCU will increase the credibility of this measure of animal biomass, improve comparisons of AMU data among animal categories and countries, and foster increased acceptance and harmonization of AMU calculations.

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